New Results on Bc in Tevatron

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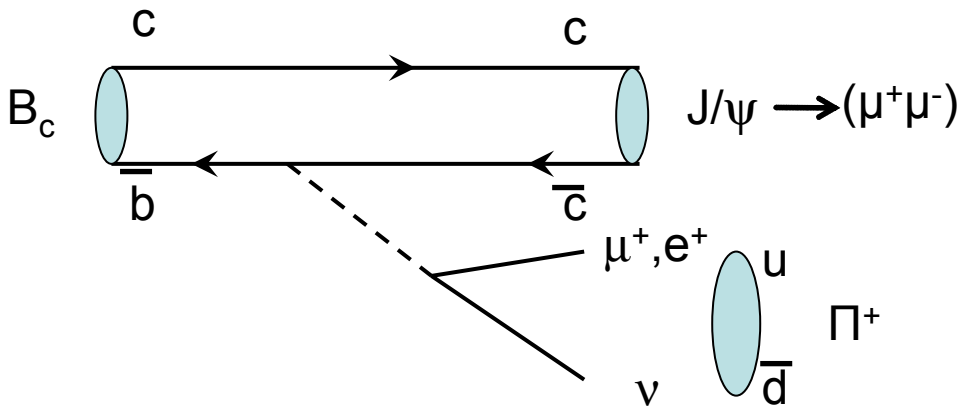
Plan

- Introduction
  - Tevatron
  - Bc properties
  - RUN I results
- Measurements
  - Production
  - Decay
  - Mass
- Summary

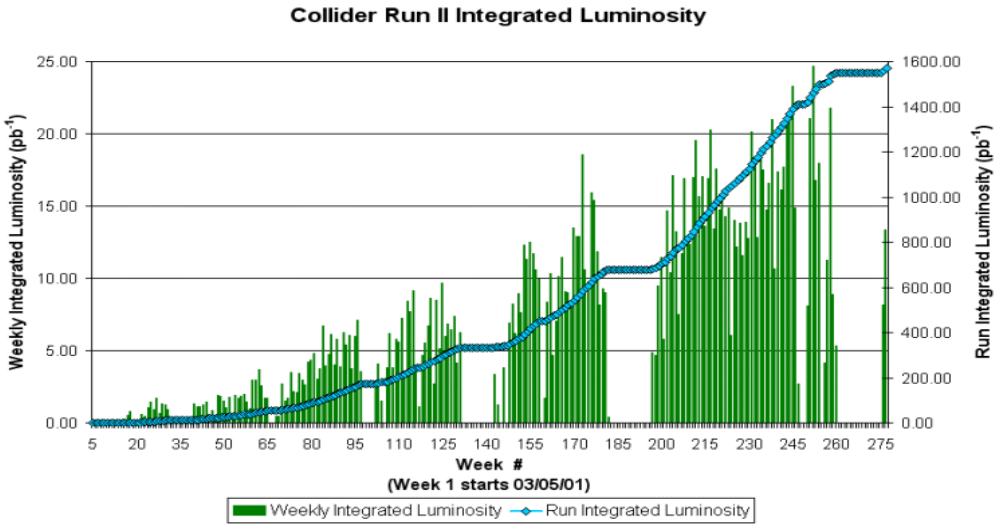


D0:
- J/ΨμX: Mass and lifetime

CDF:
- J/ΨμX: Production times BR wrt J/ΨK
- J/ΨeX: (a) Production times BR wrt J/ΨK
  (b) Lifetime
- J/Ψπ: Mass

Introduction

Tevatron in Run II:



RUN II started in 2001:

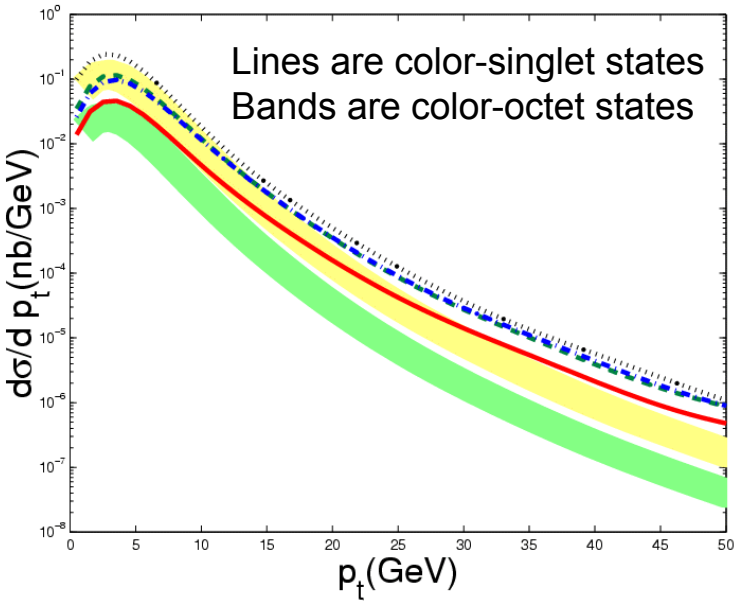
- $\sqrt{s}$=1.96 TeV
- Record luminosity:
  - $L_{ins} = 181.8 \times 10^{30} cm^{-2} s^{-1}$
- Delivered: $\int Ldt \approx 1.6\ fb^{-1}$

- Tevatron is a source of all B-hadron species: B_d, B_u, B_c, B_s and Λ_b
- $\sigma_b = 29.4 \pm 0.6 \pm 6.2\ \mu b$ ($|\eta| < 1$)
- Huge cross-section compared to B-factories but proportionally large backgrounds ($\approx 10^3$)
- Events have to be selected with specific triggers
- Easily recon-able J/Ψ with di-muon trigger

Bc Properties

- Bc is the ground state of $b\bar{c}$ system, a unique system with two heavy quarks of different flavour
  - Production:
    - Mainly gg (qq) -> Bc + b + $\bar{c}$
    - Contribution from both color-singlet and color-octet states
    - Softer p_T distribution
  - Decay: both b and c quarks can participate in Bc decay
    - Shorter c-like lifetime
    - Large number of possible final states
  - Mass: predictions from potential models and new lattice QCD calculations

Chang et al PRD 71 (2005) 074012

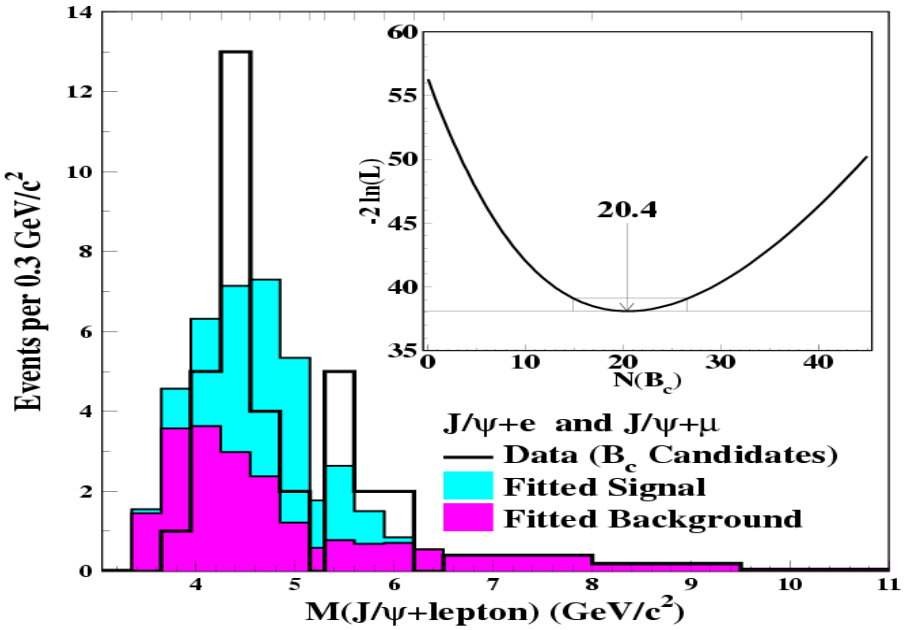


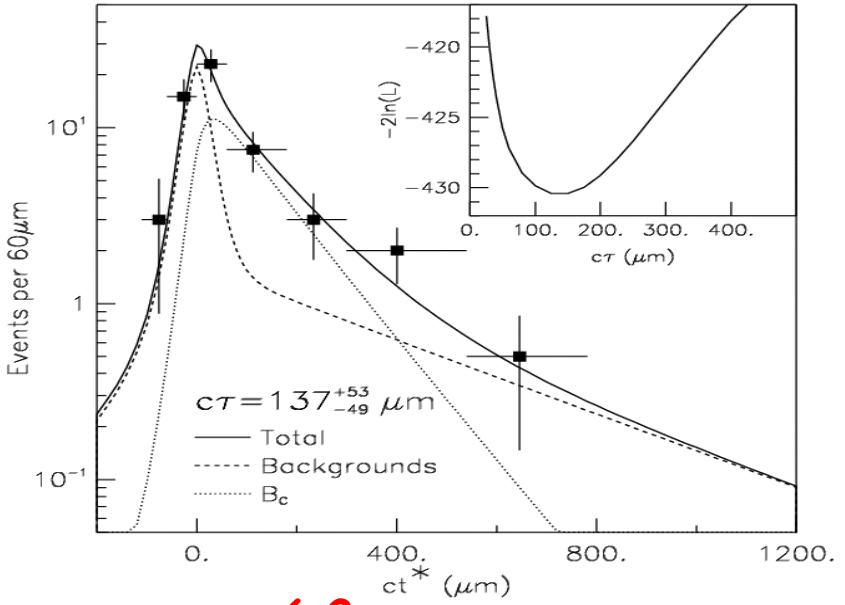
- All aspects of the theoretical work require experimental measurements and this is happening now at Tevatron!!

Bc in Run-I (91-96)

Observation and Measurements:

PRL 81, 2432 (98) and PRD 58, 112004 (98)





$20.4^{+6.2}_{-5.5}$ Signal events

$\tau = 0.46^{+0.18}_{-0.16} \pm 0.03$ ps

M=6.4 ± 0.39 ± 0.13 GeV

Production: $p_T(B) > 6$ GeV/c; $|\eta| < 0.6$

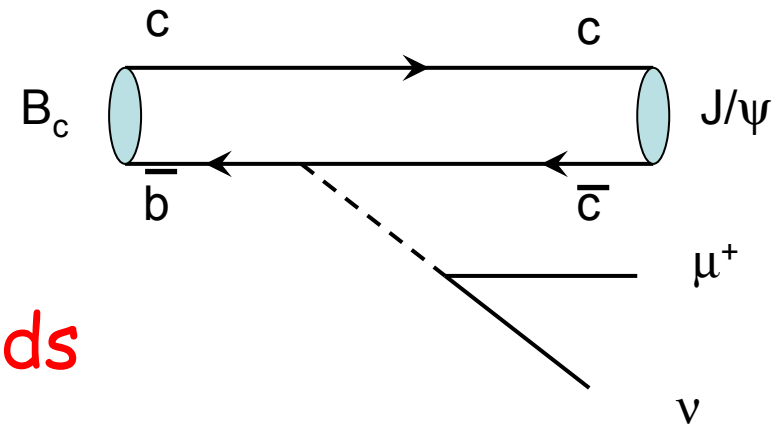
$$\frac{\sigma(B_c) \times B(B_c \to J/\psi \ell \nu)}{\sigma(B_u) \times B(B_u \to J/\psi K)} = 0.132^{+0.041}_{-0.037}\,(\text{stat}) \pm 0.031\,(\text{syst})^{+0.032}_{-0.020}$$

(cτ)

Results from DO

Three muon final state:

Analyzed 0.21 1/fb

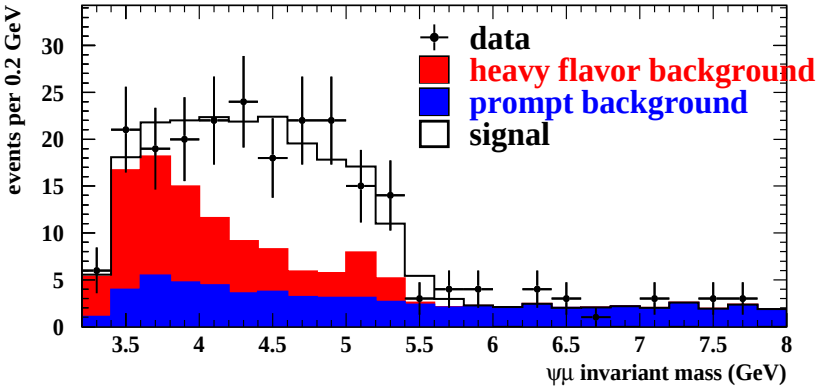


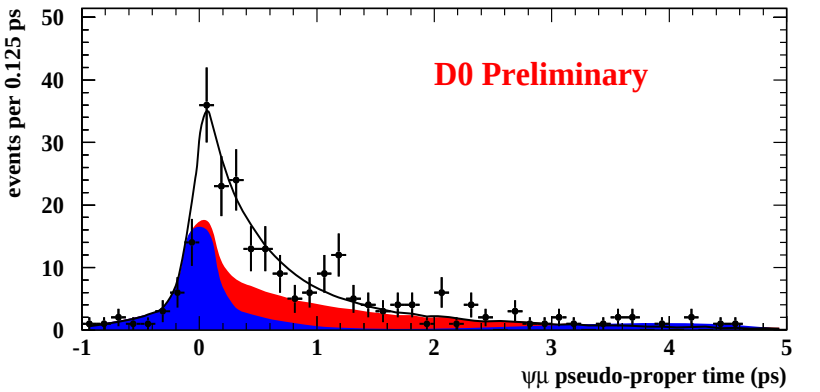
- Total 231 candidates including signal + backgrounds

- Use J/Ψ + track control sample to study background contribution:
  - Prompt background: coming from prompt J/Ψ + fake muon
  - Non-prompt or heavy flavor background: coming from J/Ψ from B mesons + fake muon

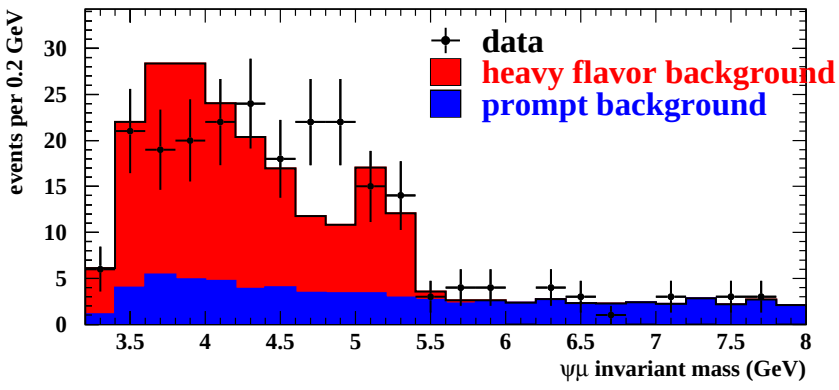
Results from D0

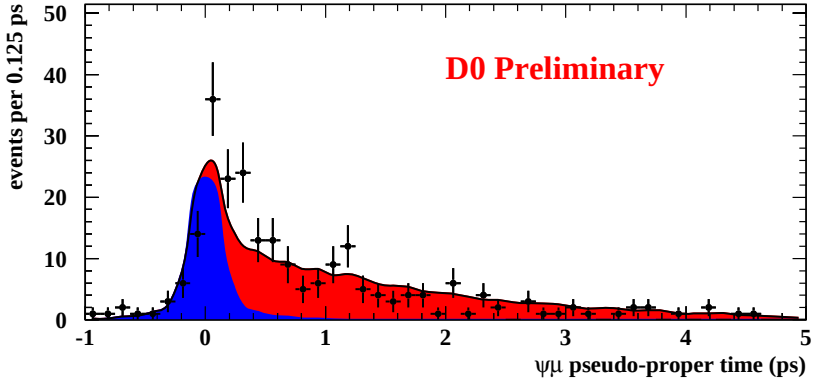
Fit with signal + background





Background only fit

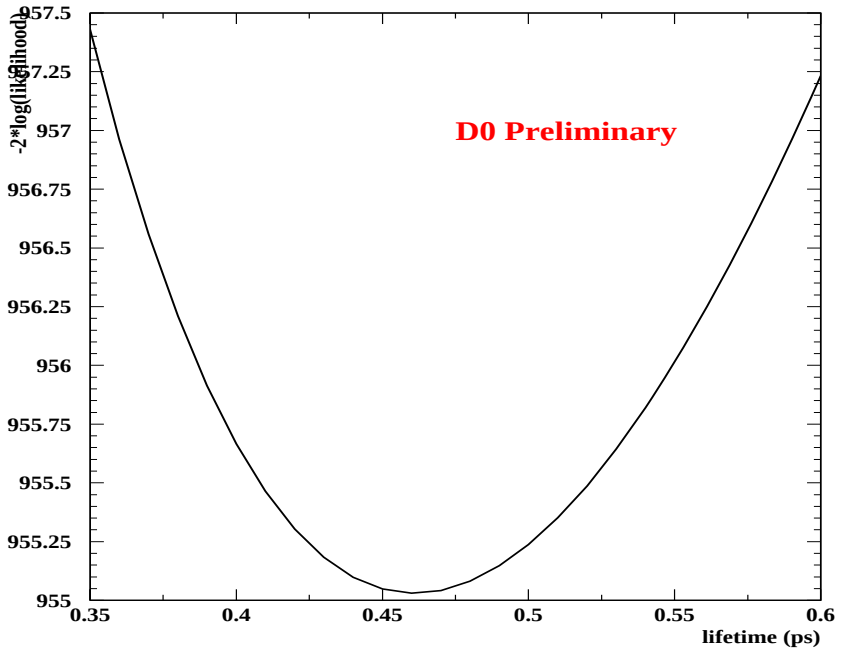


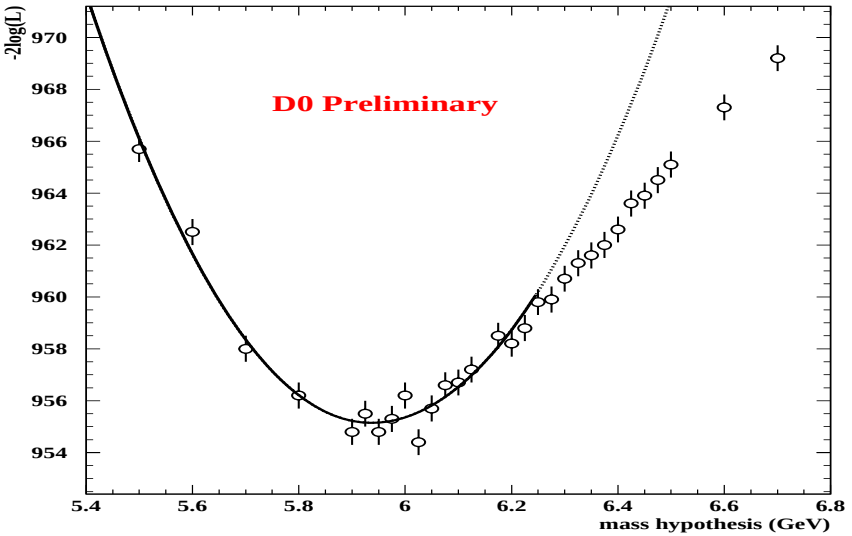


Background-only fit is poor compared with addition of signal: $\Delta 2\log(\text{likelihood})$ is 60 for 5 dof

Results from D0

- Correct for missing particle(s) from MC: k-factor
- Unbinned likelihood fit to pseudo-proper time under variety of mass hypotheses





D0 note: 4539-CONF

Results:

- $95 \pm 12 \pm 11$ candidates
- Mass: $5.95\ ^{+0.14}_{-0.13} \pm 0.34$ GeV
- Lifetime: $0.448^{+0.123}_{-0.096} \pm 0.121$ ps

Results from CDF

Bc-> J/ΨμX decay:

Analyzed 0.36 1/fb

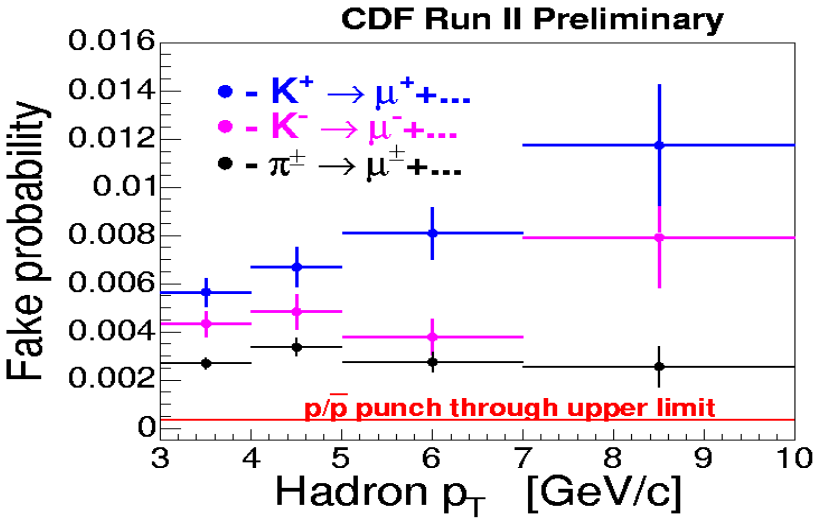
- Use 2.7 M J/Ψ events and add a muon
- Estimate contribution from backgrounds:
  - Fake muons:
    - Punch through: hadrons pass through muon detectors w/o being absorbed in calorimeters
    - Decay-in-flight: hadrons decay to muon before entering muon detectors
  - $b\bar{b}$ background: J/Ψ from b and μ from $\bar{b}$
  - Fake J/Ψ: Background events under J/Ψ mass peak

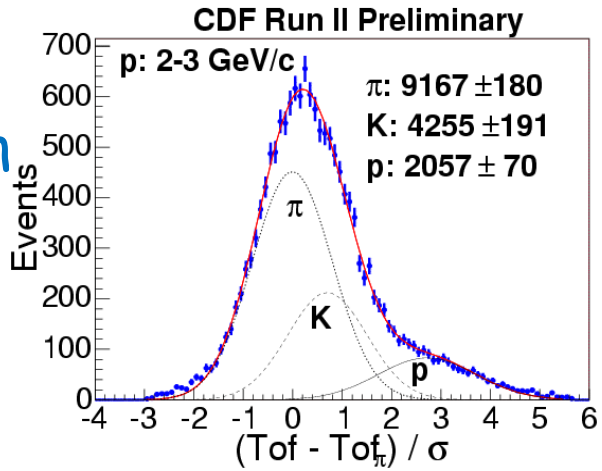
Backgrounds

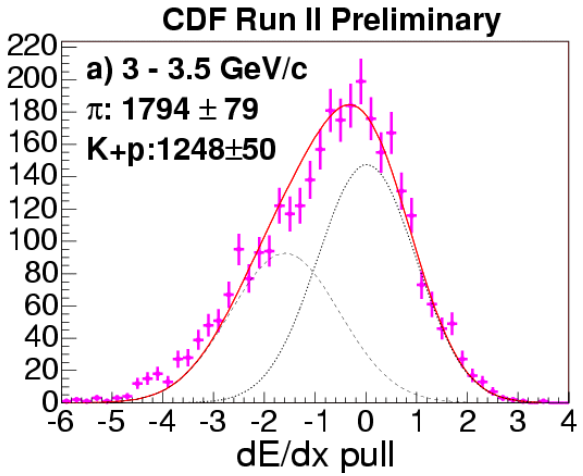
Fake muon contribution

- Select K and π from D and p from Λ sample and look for association with a muon in the muon detector
- Use PID quantities (ToF and dE/dx) to estimate composition of K, π and p

Fake muon:
16.3±2.9 events







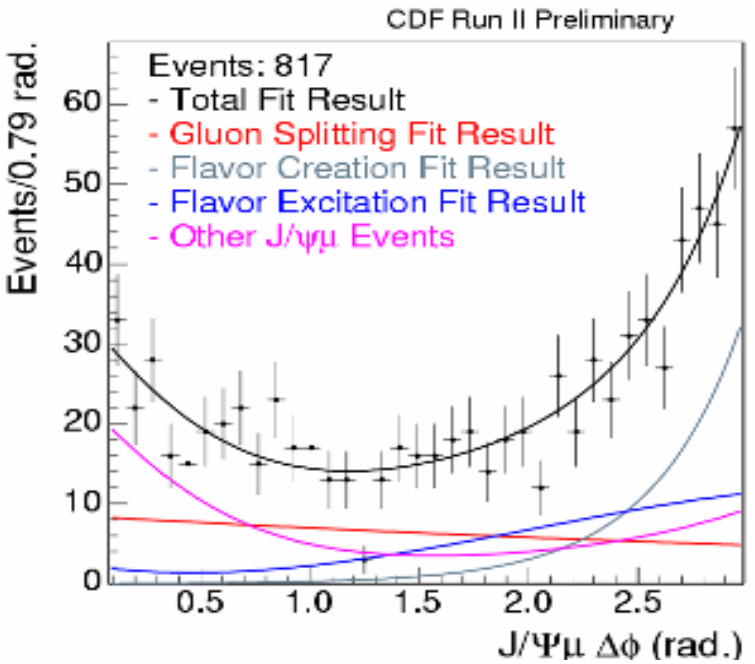
More backgrounds

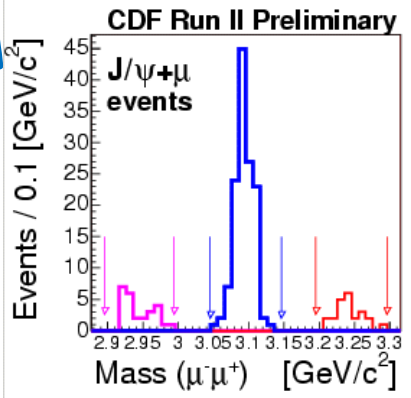
- $b\bar{b}$ background: Use Pythia MC with fractions from FC, FE and GS and normalized to B->J/ΨK data. Fit ΔΦ with data to estimate systematic

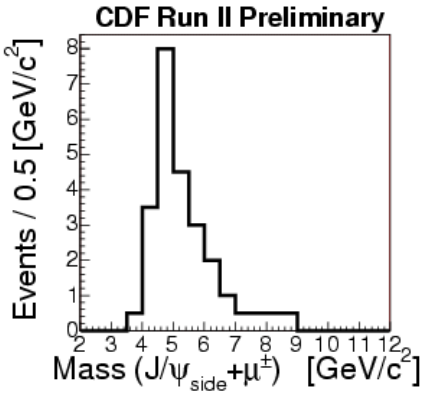
  12.7±1.7±5.7 events

- Fake J/Ψ: Estimate from sidebands by matching third track with a muon

  19.0±3.0 events



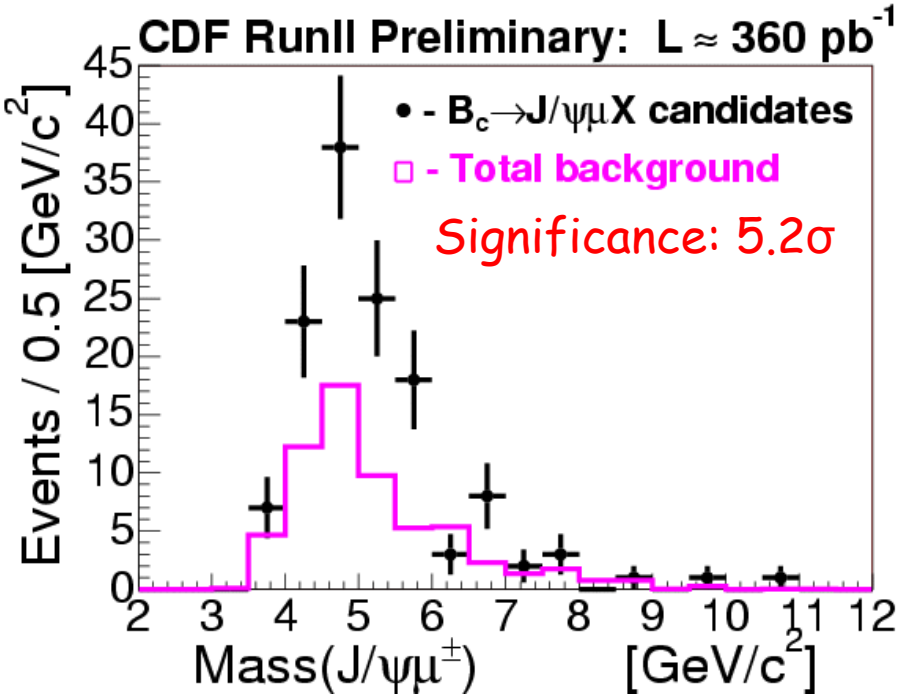




Production: Bc->J/Ψμ

- In mass window 4-6 GeV:
  - events observed = 106
  - signal events = 60
- Use MC to estimate relative efficiency and get the number of candidates from data:

CDF Note: 7649



$$\frac{\sigma(B_c) \times B(B_c \to J/\psi\, \ell\nu)}{\sigma(B_u) \times B(B_u \to J/\psi\, K)} =$$

$P_T(Bc) > 4$ GeV; $|y| < 1$

$$0.249 \pm 0.045\,(\text{stat}) \pm 0.069\,(\text{sys}) \pm {}^{0.082}_{0.033}\,(c\tau)$$

Lifetime analysis in progress

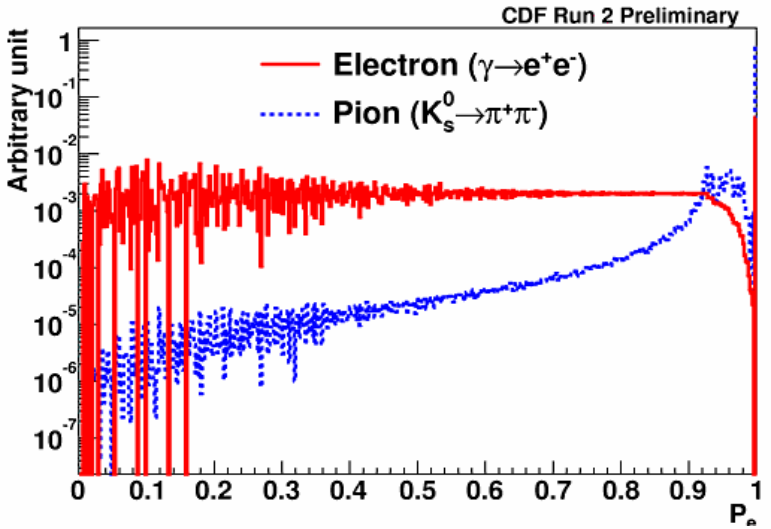
Results: Bc -> J/ΨeX

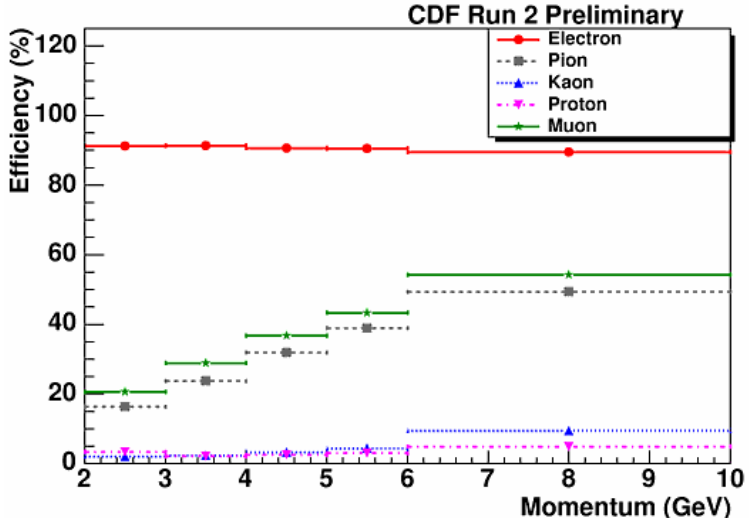
Bc -> J/ΨeX: Analyzed 0.36 1/fb

Add an electron to J/Ψ

- Electron identification:
  - Good track with p_T> 1 GeV and matched to central strip chambers and EM calorimeter
  - Cut on normalized cumulative likelihood function: Pe > 0.7 constructed from 10 em and tracking variables
  - Additional cut on specific ionization:

$$Ze=\log\frac{(dE/dX)_{measured}}{(dE/dX)_{predicted}} \; ; \; Ze/\sigma > -1.3$$



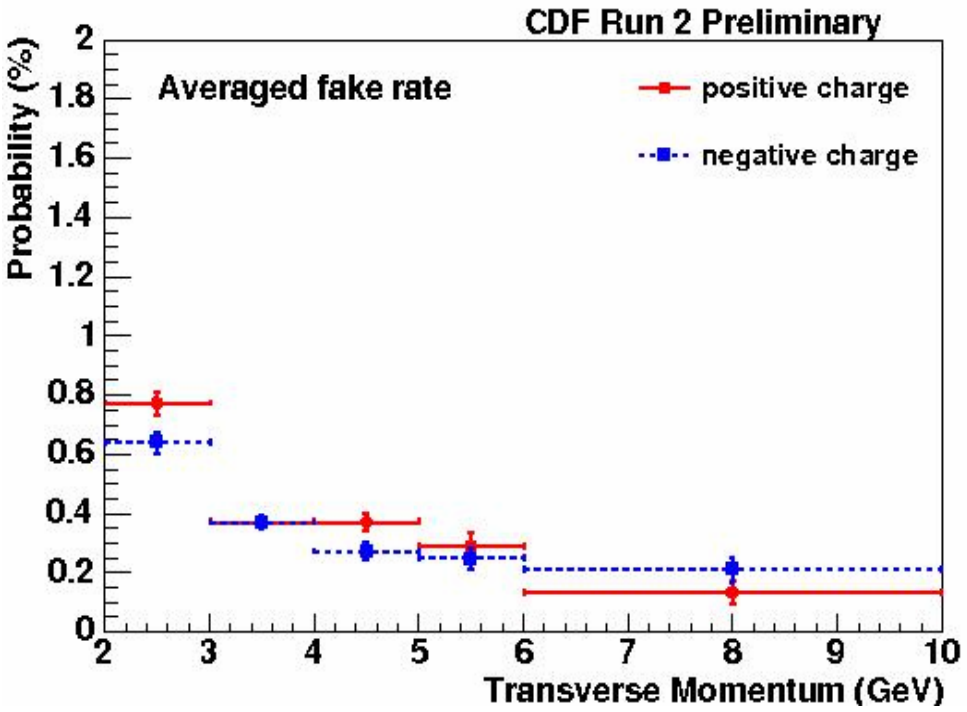


Background estimate

- Fake electron:

  Select K and π from D and p from Λ decay with e-ID and get π and (K,p) composition from Pythia MC

  15.43 ± 0.31 events



- $b\bar{b}$ background:

  Use Pythia MC with fractions of FC, FE and GS and normalized to J/ΨK data

  33.63 ± 2.20 events

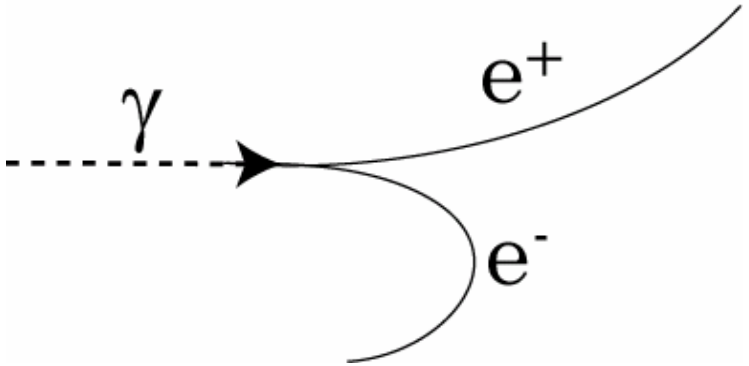
Photon conversion

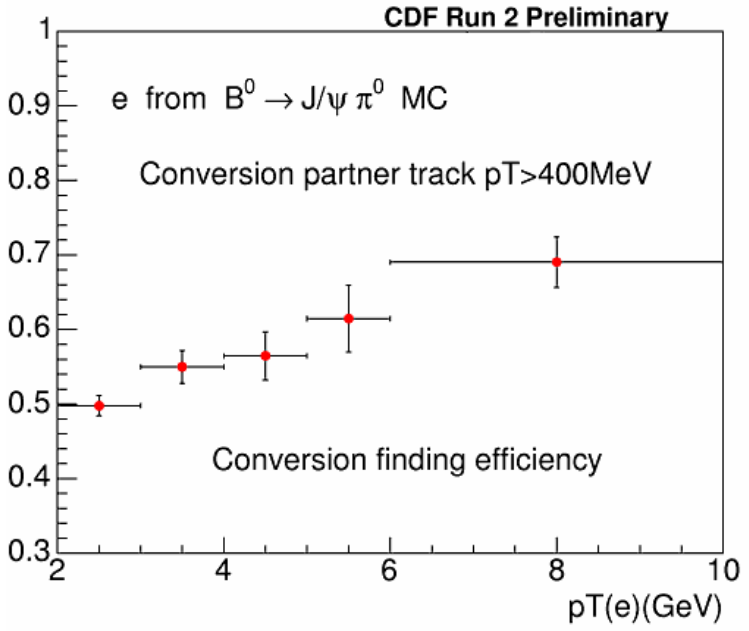
Residual photon conversion:

- Removed during J/Ψe sample selection
- Evaluate the conversion finding efficiency from MC ($B \to J/\Psi \pi^0$; $\pi^0 \to \gamma\gamma$; $\gamma \to e^+e^-$)
- Estimate residual conversion electrons from J/Ψ+tagged conversion:

$$N_{res} = N_{con} \times (1-\varepsilon_{con})/\varepsilon_{con}$$

14.54 ± 4.38 events





Production: Bc->J/Ψe

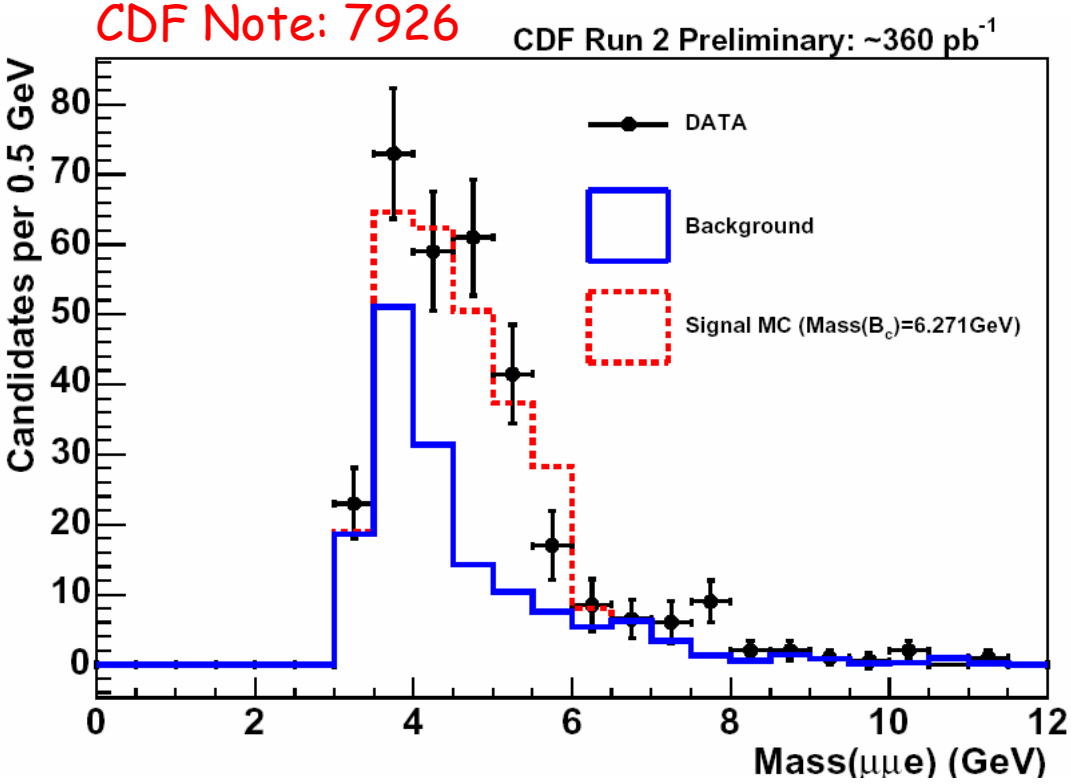
- Observed:

  178.5 ± 14.7
- Backgrounds:

  63.6 ± 4.9 ± 13.6
- Excess:

  114.9 ± 15.5 ± 13.6
- Significance: 5.9 σ
- Production:

CDF Note: 7926



$$\frac{\sigma(B_c) \times B(B_c \to J/\psi\, \ell\nu)}{\sigma(B_u) \times B(B_u \to J/\psi\, K)} = 0.282 \pm 0.038(\text{stat.}) \pm 0.035(\text{yield}) \pm 0.065(\text{acc})$$

$p_T(B) > 4$ GeV/c and $|y| < 1$

Lifetime: Bc->J/Ψe

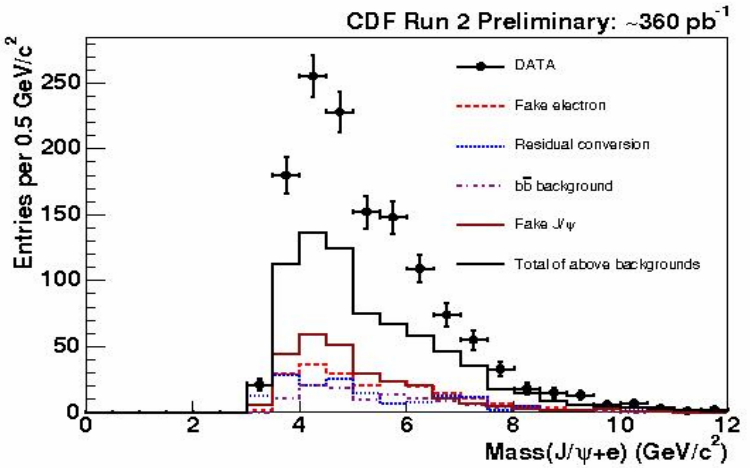
- Relax lifetime related cuts to add prompt for better parameterization; zero lifetime with Gaussian resolution

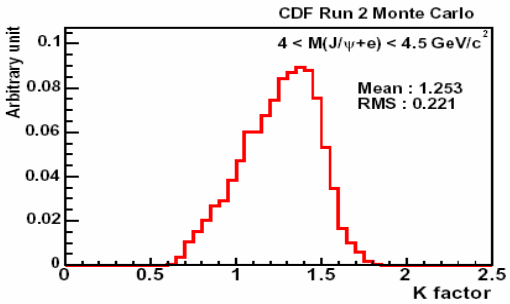
- Missing particles (neutrino etc): (pseudo-) proper decay length:

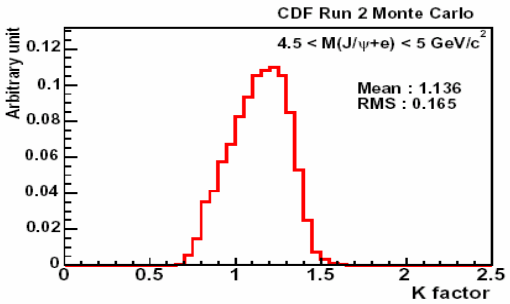
$$c\tau = L_{xy}.\frac{M(J/\Psi+e)}{p_T(J/\Psi+e)}.K$$

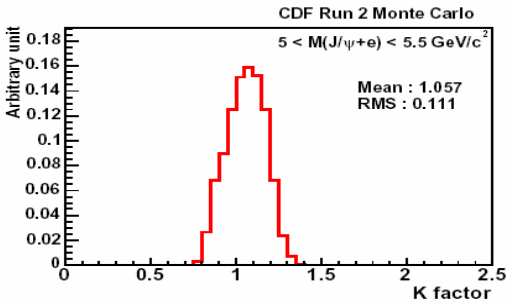
Calculate from MC:

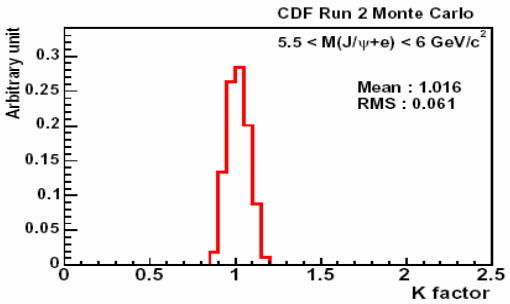
$$K = \frac{p_T(J/\Psi+e)}{p_T(Bc)}\,\frac{M(Bc)}{M(J/\Psi+e)}$$





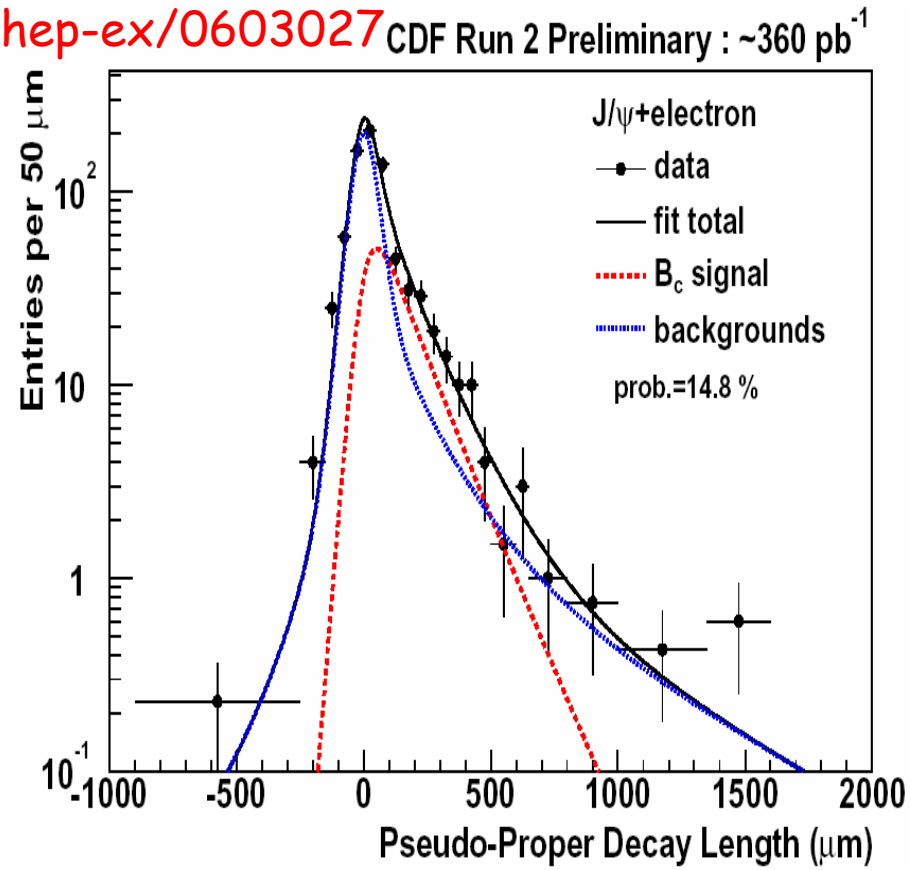






Lifetime: Results

- Un-binned likelihood fit to signal and background
  - Signal: pure exponential convoluted with Gaussian and K-factor dist from MC
  - Backgrounds: fractions and decay length from background samples



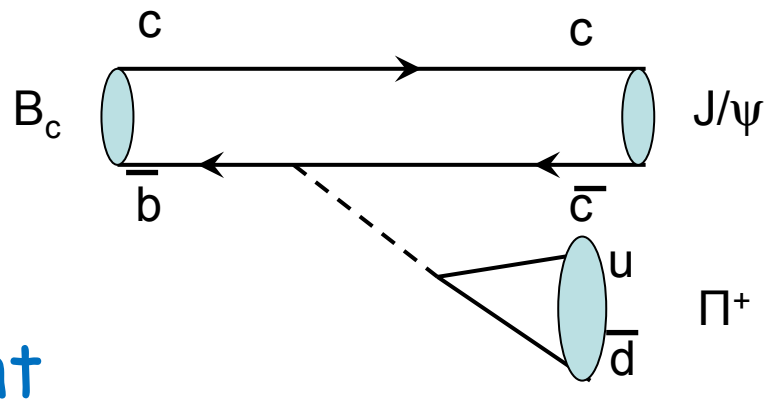
$\tau(Bc)=0.474^{+0.073}_{-0.066}\pm0.033$ ps

$c\tau(Bc)=142.1^{+21.9}_{-19.7}\pm10.0$ μm

Mass measurement

Fresh from the oven:

Analyzed with 1.1 fb^{-1}



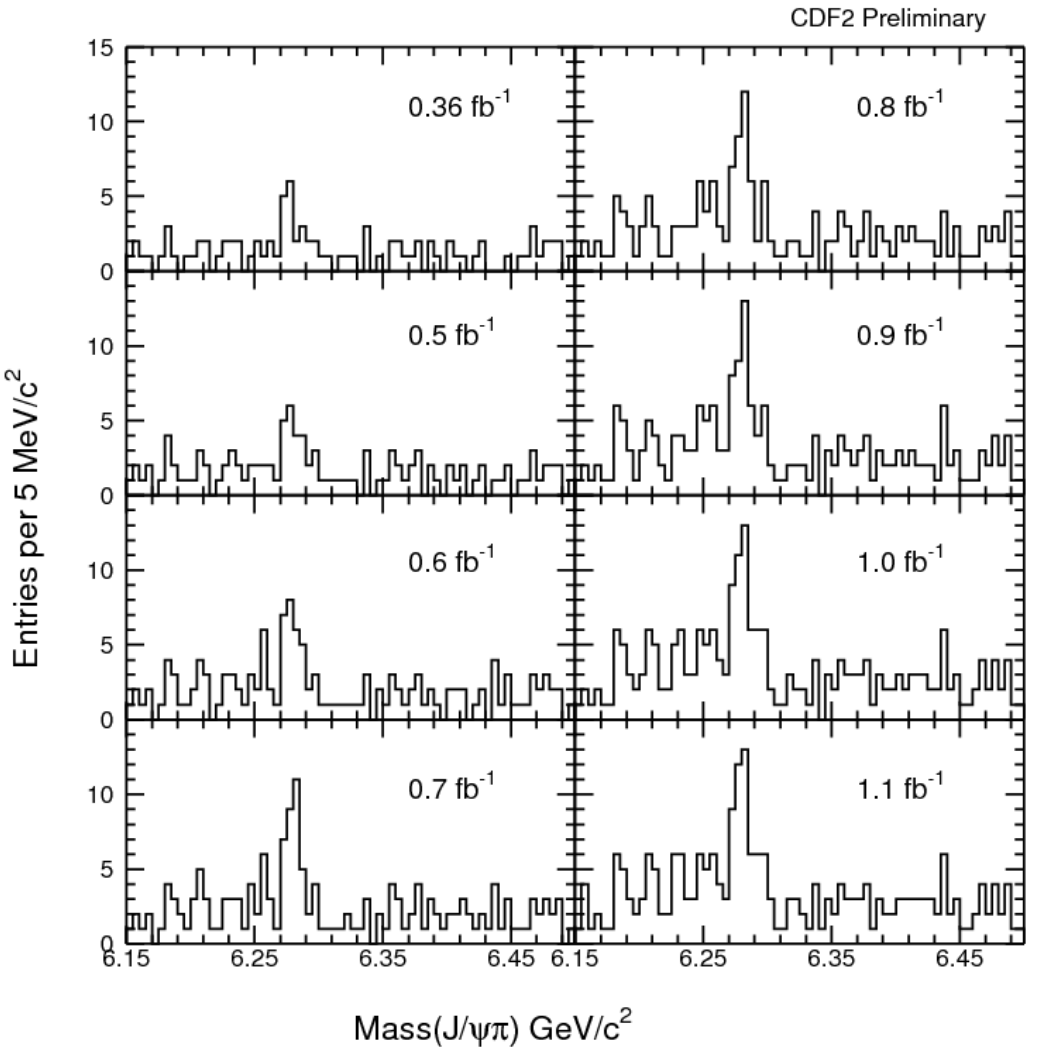
- Fully reconstructed decay mode – precise measurement of mass possible
- Blind analysis: Tune selection on data Bu -> J/Ψ K then replace K with π
- After approval "open box" and wait for significant excess of events
- Measure mass of Bc

Mass measurement

Some selection cuts:

- $p_T(K) > 1.7$ GeV
- $p_T(B) > 5$ GeV
- $|M(\mu\mu) - M(J/\Psi)| < 70$ MeV
- Decay-length > 80 μm
- IP_{singf}(K wrt PV) > 2.5σ
- pointing angl e β < 0.4 rad

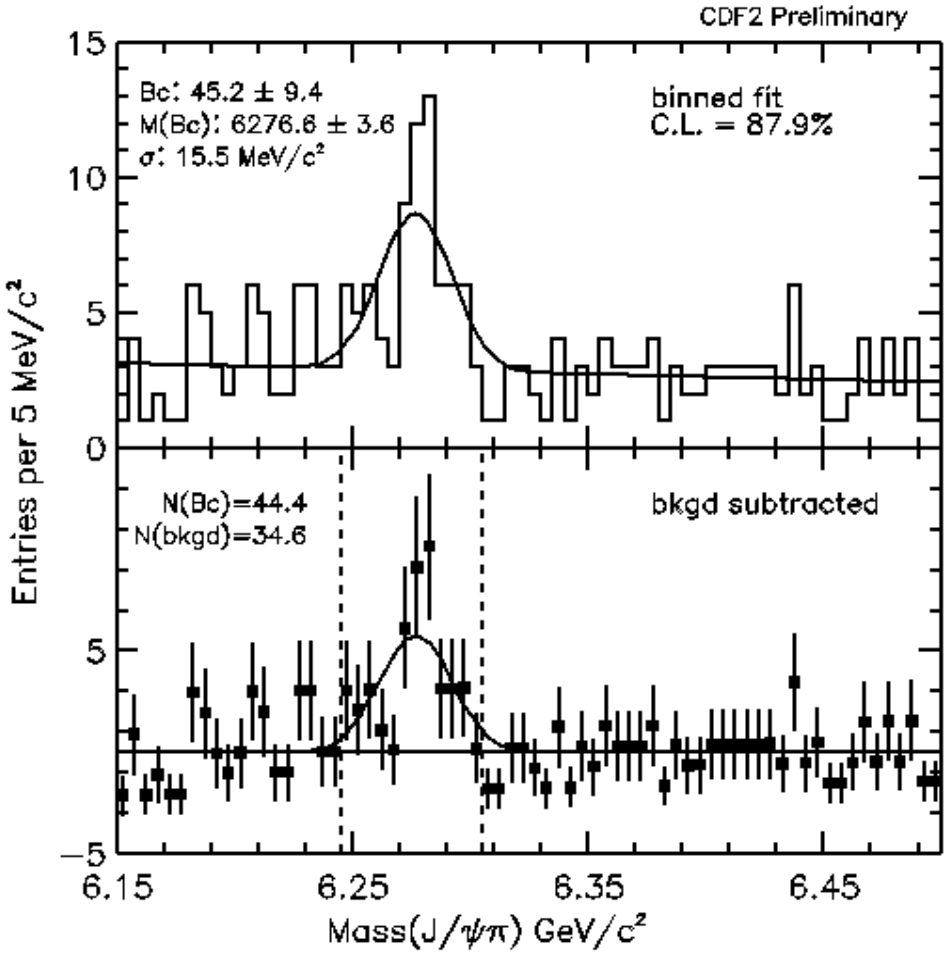
Clear indication of signal build-up with the accumulation of more and more data



Mass measurement

Binned fit and Poisson probability

- Binned fit using linear bkg and Gaussian signal with fixed width 15.5 MeV/c^2
- Calculate siganl and bkg in 2σ region
- Poisson probability that 34.6 background events can fluctuate to total number of events exceeding 79 is 3.0×10^{-11} correspond to 6.5σ
- Several other studies confirm excess above 6σ



Mass measurement

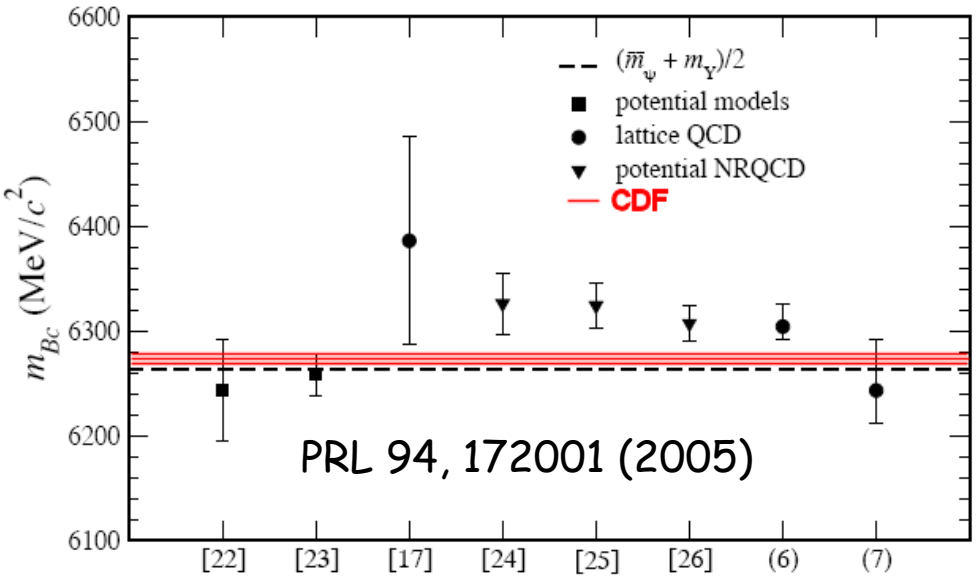
Mass determination:

Unbinned log likelihood fit with a linear background + Gaussian signal

parametrs: mass, fraction, slope, σ scale (1.56) for mass resolution

Observed signal: 49.1±9.7
Backgrounds: 34.1

Lattice QCD calculation



$M(Bc)_{LAT}$ = 6304 ± 12 MeV/c^2

$M(Bc)_{CDF}$ = 6276.5 ± 4.0 (stat) ± 2.7 (sys) MeV/c^2

Nuclear Physics B (Proc. Suppl.) 156 (2006) 240-243 and FERMILAB-CONF-06-074-E (Apr 2006)

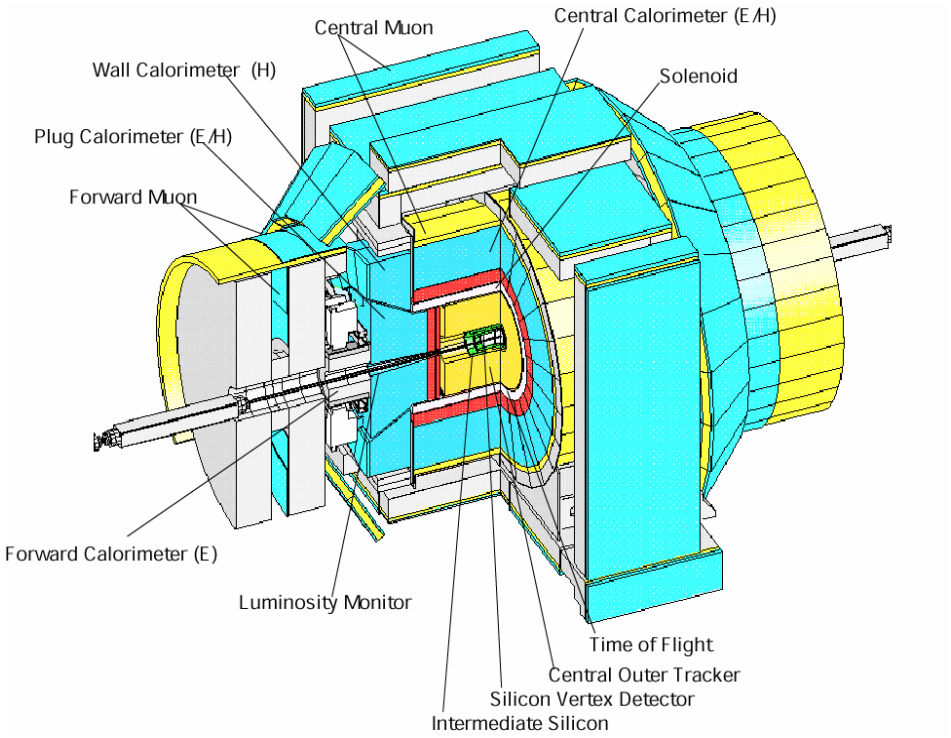
Summary

- Bc study is happening at Tevatron
- Semi-leptonic decays observed > 5σ
  - D0: Analyzed J/Ψμ with 0.21 fb^{-1}
  - CDF: Analyzed J/Ψμ and J/Ψe with 0.36 fb^{-1}
- Fully reconstructed mode J/Ψπ > 6.5σ
  - CDF has measured precision mass with 1.1 fb^{-1}
- Coming soon:
  - Lifetime form J/Ψμ
  - Production spectrum

Back-up

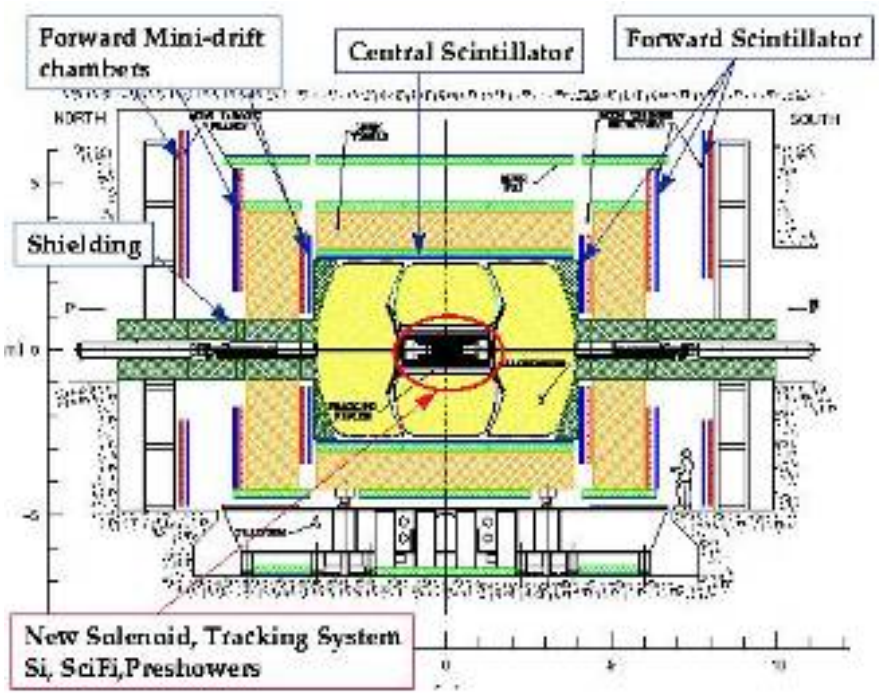
Detectors

Excellent tracking system in 1.4 T consists of 5-layers of silicon + ISL + COT and drift muon chambers CMU + CMX |η| < 0.6 (1.0)



CDF Detector

Excellent coverage of tracking and muon system
Forward muon system with |η| < 2; good shielding
4-layers silicon and 16-layers Fibre-trackers in 2T



D0 Dtector

DO Results

Systematic errors

	Mass (GeV/c^2)	Lifetime (ps)	# Signal
Statistical	$^{+0.14}_{-0.13}$	$^{+0.118}_{-0.094}$	11.8
Limited statistics of background sample	0.06	0.013	3.0
Fraction non-resonant $B_c^+ \to J/\psi\mu^+\pi^0\nu$	0.14	0.022	6.7
Feed-down fraction from $B_c^+ \to J/\psi(2S)\mu^+\nu$	0.08	0.017	5.4
MC signal modeling: phase space vs. ISGW	0.16	0.023	4.4
MC signal modeling: HQET vs. ISGW	0.06	0.007	1.8
B_c p_T spectrum	0.05	0.004	0.8
Momentum binning	0.14	0.062	0.4
Alignment and primary vertexing algorithm	0.08	0.085	3.1
$\mathcal{P}_{\rm fit}$ selection criteria	0.06	0.028	–
Sensitivity to prompt/heavy relative bkgd fractions	0.15	0.036	–
Total systematic error	0.34	0.121	10.7

Systematic errors

catalog	description	Fitted $c\tau$ (μm)	$\Delta c\tau$ (μm)
K-factor	$M(B_c) = 6.4$, 6.2 GeV	$140.4^{+21.7}_{-19.5}$, $143.0^{+22.0}_{-19.8}$	± 1.7
K-factor	$\tau(B_c) = 0.5$, 0.7 ps	$141.9^{+21.9}_{-19.6}$	± 0.2
K-factor	$H_b \to J/\psi X$ spectrum	$140.8^{+21.7}_{-19.5}$	± 1.3
K-factor	Inclusive $J/\psi X e\nu$	$140.5^{+21.7}_{-19.5}$	± 1.6
K-factor	trigger simulation	$142.4^{+21.9}_{-19.7}$	± 0.3
			K-factor sub-total $\Delta c\tau = \pm 2.7$
$\mathcal{F}_{fake-e}$	Use J/ψ+trk shape directly	$140.6^{+21.5}_{-19.4}$	-1.5
$\mathcal{F}_{fake-J/\psi}$	use $J/\psi + e$ sideband	$136.0^{+24.8}_{-22.6}$	-6.1
$\mathcal{F}_{conv-e}$	Use tagged conv-e shape directly	$141.2^{+21.7}_{-19.5}$	-0.9
$\mathcal{F}_{conv-e}$	use J/ψ+conv-e sideband	$144.8^{+21.5}_{-19.3}$	$+2.7$
$\mathcal{F}_{b\bar{b}}$	use FE only	$150.2^{+17.5}_{-15.9}$	$+8.1$
$\mathcal{F}_{b\bar{b}}$	use GS only	$138.3^{+16.6}_{-15.0}$	-3.8
$\mathcal{F}_{b\bar{b}}$	No error scaling in MC	$140.9^{+21.6}_{-19.5}$	-1.2
			Background shapes sub-total $\Delta c\tau = (+8.5, -7.5)$
L_{xy} resolution	extra Gaussian/symmetric exponential	$137.0^{+21.9}_{-19.8}$, $136.5^{+21.9}_{-19.8}$	-5.6
L_{xy} resolution	Punzi effect	$137.3^{+22.1}_{-19.4}$	-4.8
L_{xy} resolution	silicon alignment		± 1
			L_{xy} resolution sub-total $\Delta c\tau = (+1.0, -7.4)$
			Total systematic error $\Delta c\tau = (+9.0, -10.9)$